Analysis and High-Resolution Modeling of Tropical Cyclogenesis during the TCS-08 and TPARC Field Campaign

PI: Tim Li
IPRC/SOEST, University of Hawaii at Manoa
1680 East-West Road, POST Building 409B
Honolulu, Hawaii 96822
Phone: (808) 956-9427 fax: (808) 956-9425 e-mail: timli@hawaii.edu

Co-PI: Melinda S. Peng
Naval Research Laboratory
Monterey CA 93943-5502
Phone: (831) 656-4704 fax: (831) 656-4769 e-mail: melinda.peng@nrlmry.navy.mil

Award Number: N000140810256

LONG-TERM GOALS

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved understanding of the fundamental mechanisms involved. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to the lack of skill in the prediction of TC genesis and intensity is the lack of observations prior to and during TC genesis and intensification periods and the inadequate understanding of physical mechanisms that control the cyclogenesis and intensity change. The TCS-08 and TPARC field campaign provide an unprecedented opportunity for us to gain the first-hand insight of observed characteristics of TC genesis in western Pacific and to compare them with high-resolution model simulations. By analyzing and assimilating these data, we intend to understand the physical mechanisms that involve the TC internal dynamic and thermodynamic processes, external forcing, and scale interactions. Only after thoroughly understanding these processes, can one be able to tackle the weaknesses in the current state-of-art weather forecast models.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Analysis and High-Resolution Modeling of Tropical Cyclogenesis during the TCS-08 and TPARC Field Campaign**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,7 Grace Hopper Avenue,Monterey,CA,93943-5502**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

OBJECTIVES

The objective of this project is to investigate what initial precursor conditions (e.g., thermodynamic variables such as moisture and temperature vs. dynamic variables such as vorticity and surface wind speed) are crucial in determining TC genesis efficiency, using a cloud-resolving (2-km) WRF model. Taking advantage of 2008 TCS-08 and TPARC observational campaign, we plan to produce a 3D high-resolution reanalysis product for the western North Pacific (WNP) during the intense observational campaign period. We plan to conduct high-resolution model cyclogenesis forecast experiments with use of either the global reanalysis data or the data assimilation product mentioned above as initial conditions. We will examine how the cyclogenesis forecast may be significantly improved with a better description of the dynamic and thermodynamic precursor signals.

APPROACH

We plan to conduct the following two major tasks: 1) high-resolution cyclogenesis simulations to understand the dependence of the model TC genesis efficiency on initial vertical vorticity/humidity profiles, and 2) typhoon data assimilation with use of in-situ observational data collected during the TCS-08 and TPARC campaigns and the analysis of the data product to reveal structure and evolution characteristics during the TC genesis period.

For the first task, we plan to use multi-nested WRF model (with 2 km resolution in the innermost mesh) to simulate idealized and real-case cyclogenesis events. Through the diagnosis of the model outputs, we intend to understand the common and different development characteristics associated with cyclogenesis in an environment with a near bottom vortex (EBV) and an environment with a mid-level vortex (EMV). The genesis time for each model run will be defined based on an objective way. A concept of the cyclogenesis efficiency (which is related to the initial environmental dynamic and thermodynamic conditions) will be introduced. A number of idealized experiments will be designed to illustrate the relative importance of initial volumn-integrated absolute vorticity, PBL parameters, surface fluxes, and vertically integrated relative humidity in determining the TC genesis efficiency.

For the second task, because the TCS-08 and TPARC campaign provides variety types of in-situ data at irregular spatial and temporal intervals, we intend to construct a high-resolution regular-grid reanalysis product that combines all types of (field and remote-sensing) observations together. The data assimilation system to be used is either NRL Atmospheric Variational Data Assimilation System (NAVDAS) or WRF 3DVar system.

Collaborating with NRL-MRY scientists (Dr. Nancy Baker), we have implemented the direct satellite radiance assimilation technique into the COAMPS NAVDAS. The proposed reanalysis effort will cover the entire TCS-08 and TPARC campaign period, with a horizontal resolution of 10-30 km and a time interval of 3 hours. Our assimilation strategy is to combine the in-situ observations (such as ELDORA radar, Doppler wind lidar, dropsondes and driftsondes) with multi satellite products.

WORK COMPLETED

In the high-resolution TC simulation part, both real-case and idealized simulations of TC genesis in the western North Pacific are conducted. A paper about real-case simulation of Typhoon Prapiroon (2000) associated with the Rossby wave energy dispersion of a pre-existing TC was published in 2010 Monthly Weather Review. Another paper entitled “What causes the extremely heavy rainfall in Taiwan during Typhoon Morakot (2009)” was published in 2010 *Atmospheric Science Letters*. A manuscript entitled “Tropical cyclone genesis efficiency: Mid-level versus bottom precursor vortex” has been submitted to Monthly Weather Review and is currently under revision.

Meanwhile, data assimilation with use of TCS-08 in-situ observational campaign data (including ELDORA radar, Doppler wind lidar, dropsondes and driftsondes) and multi satellite products has been conducted. The data are currently available at IPRC/UH website.

RESULTS

Cloud resolving WRF model is used to investigate the tropical cyclone genesis efficiency in an environment with a near bottom vortex or an environment with a mid-level vortex. Five experiments were designed with different initial vertical vorticity and moisture profiles. In the first experiment (MID_VORTEX), we mimic a mid-level precursor condition, by specifying an initial cyclonic vortex that has a maximum vorticity at 600 hPa and corresponds to a maximum wind speed of 8 m s^{-1} at a radius of 100 km and a size of 500 km radius where the wind vanishes. The vorticity gradually decreases both upward and downward, and vanishes at the surface. In the second experiment (BTM_VORTEX), an initial maximum precursor perturbation with a maximum wind speed of 8 ms^{-1} is located at the surface. Figures 1a and 1b show the vertical-radial cross section of the tangential wind of these initial vortexes. The third and the fourth experiment contain a shallow mid-level vortex (SHAL_MID) and a shallow bottom vortex (SHAL_BTM), respectively, to identify the PBL effects and to better separate the mid-level and bottom vortices. Their vertical wind profiles are shown in

Figs. 1c and 1d. The fifth experiment (MOIST) has the vortex profile as the MID_VORTEX except with a greater moisture to investigate the dependence of TC genesis efficiency on the humidity profile.

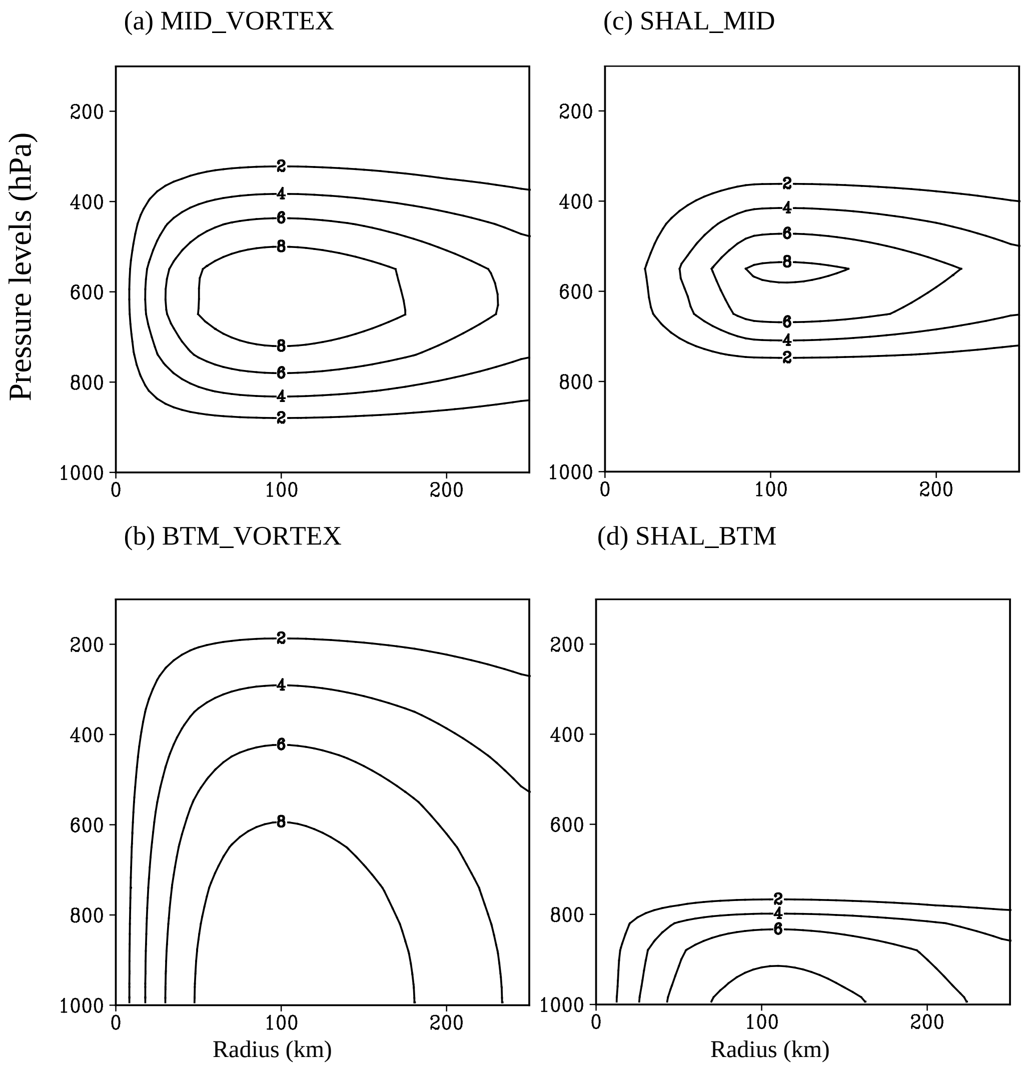

Fig. 1 The vertical-radial cross section of tangential velocity (ms^{-1}) of the initial vortex in (a) MID_VORTEX, (b) BTM_VORTEX, (c) SHAL_MID and (d) SHAL_BTM.

All experiments above are able to develop a realistic and similar tropical cyclone, although the time taken is different. These time differences represent the genesis efficiency of the initial setup of the precursor vortex or the environmental moisture profile. It is found that all experiments share the following development characteristics: 1) a transition from non-organized cumulus-scale (~5 km) convective cells into an organized meso-vortex-scale (~50 km) system through upscale cascade and system scale intensification (SSI) processes, 2) the establishment of a nearly saturated air column prior to a rapid drop of the central minimum pressure, and 3) a convective-stratiform phase transition.

The numerical experiments above show that the genesis timing depends crucially on the initial vertical moisture and vorticity profiles. Based on these experiments and following the formula of the genesis potential index by Emanuel and Nolan (2004), we introduce a genesis efficiency index (GEI) to quantify the impact of initial vorticity and moisture profiles on the cyclogenesis. The key parameters in the GEI include the column integrated (1000-200hPa) absolute vorticity, relative vorticity at top of the planetary boundary layer (PBL), and vertically integrated (1000-500hPa) relative humidity (RH). Figure 2 shows that the GEI presents well the model simulated genesis feature. We found that with a similar column integrated (1000-200hPa) absolute vorticity, a bottom precursor vortex has a higher genesis efficiency than a mid-level vortex.

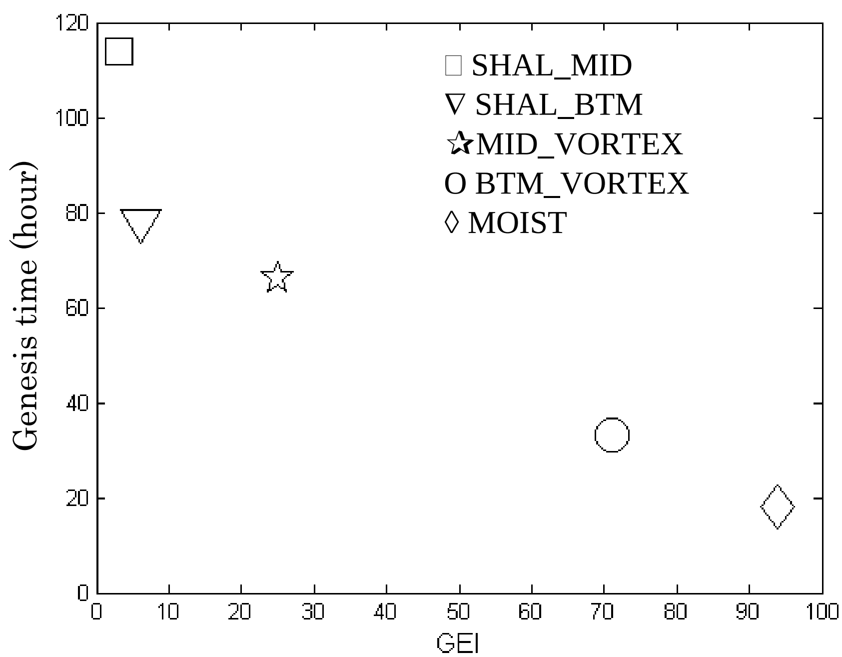

Fig. 2 Relationship between the GEI and the genesis time in the five experiments.

A salient feature among all five experiments above is a close relationship between the deepening of a moist layer and cyclogenesis time. For instance, in MID_VORTEX, there is a steady increase of the moist layer in the core region during hour 24-60. The 90% RH layer thickens from 900 hPa at hour 24 to about 500 hPa at hour 60. It is the establishment of this near-saturation air column that signifies the next development stage: deepening of cyclonic vorticity and a rapid drop of minimum sea level pressure. In all five experiments above, the genesis time occurs shortly after a near-saturated air column is set up. This preconditioning of the deep moist layer in the core region was also found in Nolan (2007) with different model physics. Figure 3 illustrates the evolution of the vertically (1000-500 hPa) integrated RH averaged in the core region (within a 100km x 100km domain) and its relationship with the TC genesis. In all five experiments, the genesis start shortly after the column averaged RH reaching 90%, confirming that the establishment of a near-saturated deep air column is indeed a precondition for cyclogenesis.

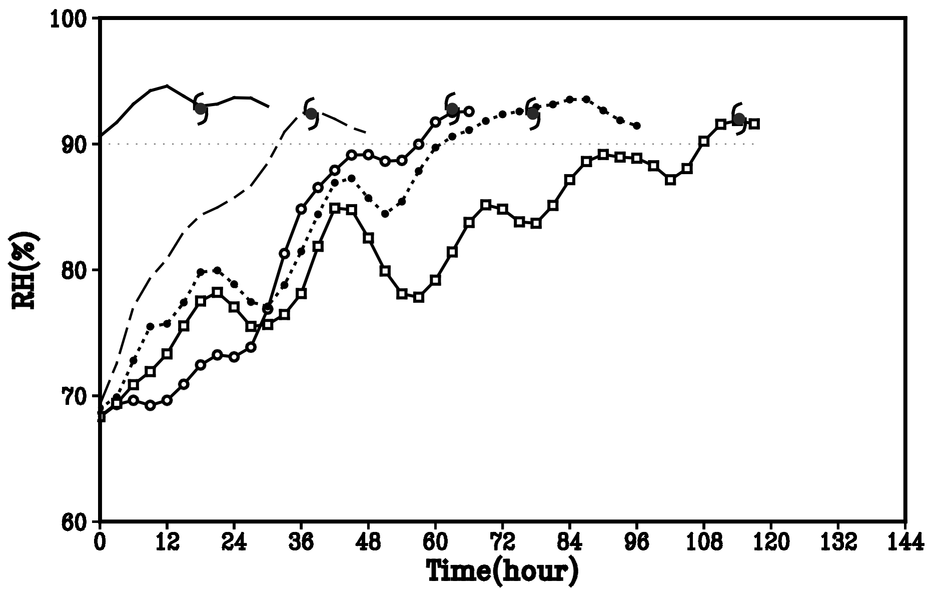

Fig. 3 Time evolution of the column averaged $\overline{RH}$ (from the surface to 500hPa) in MOIST (solid line), BTM_VORTEX (long dashed line), MID_VORTEX (solid line with open circle), SHAL_BTM (dotted line with solid circle), SHAL_MID (solid line with open square), respectively. The hurricane symbols represent the genesis time of each experiment.

IMPACT/APPLICATIONS

The investigation of the cyclogenesis efficiency and the establishment of the western Pacific typhoon reanalysis product are critical to improve our current understanding of dynamics of cyclogenesis and promote a more skillful numerical weather prediction of TC genesis and intensity change.

TRANSITIONS

Results from this study may lead to improvements in the NOGAPS and COAMPS prediction of tropical cyclone genesis and intensity change. The data assimilation strategy for TC dynamic initialization may transition into a 6.4 project.

RELATED PROJECTS

This project is closely related to the ONR funding entitled “Western Pacific tropical cyclone reanalysis with the NRL Atmospheric Variational Data Assimilation System (NAVDAS)” in which we conduct the typhoon reanalysis for 2005-2007. Knowledge gained from this project will help assimilate TCS-08 and TPARC observational data and improve the model initial condition for TC prediction.

PUBLICATIONS

In the following we list the publications in 2010 that are fully or partially supported by this ONR grant during the past year:

Li, T., M.-H. Kwon, M. Zhao, J.-S. Kug, J.-J. Luo, and W. Yu, 2010: Global warming shifts Pacific tropical cyclone location. *Geophys. Res. Lett.*, in press.

Zhou, C. and T. Li, 2010: Upscale feedback of tropical synoptic variability to intraseasonal oscillations through the nonlinear rectification of the surface latent heat flux. *J. Climate,* in press.

Chen, J.-M., T. Li, and C.-F. Shih, 2010: Tropical Cyclone and Monsoon Induced Rainfall Variability in Taiwan. *J. Climate,* in press.

Zhu, W., T. Li, X. Fu, and J.-J. Luo, 2010: Influence of the Maritime Continent on the Boreal Summer Intraseasonal Oscillation. *J. Meteor. Soc. Japan*, 88, in press.

Gu, D., T. Li, Z. Ji, and B. Zheng, 2010: On the Western North Pacific Monsoon, Indian Monsoon and Australian Monsoon Phase Relations. *J. Climate*, in press.

Hong, C.-C., T. Li, H. Lin, and Y.-C. Chen, 2010: Asymmetry of the Indian Ocean Basin-wide SST Anomalies: Roles of ENSO and IOD. *J. Climate*, in press.

Hendricks, E.A., M. S. Peng, B. and Fu, and T. Li, 2010: Quantifying environmental control on tropical cyclone intensity change. *Mon.Wea.Rev*., in press.

Wu, B., T. Li, and T. Zhou, 2010: Relative contributions of the Indian Ocean and local SST anomalies to the maintenance of the western North Pacific anomalous anticyclone during El Niño decaying summer. *J. Climate*, 23, 2974-2986.

Wu, B., T. Li, and T. Zhou, 2010: Asymmetry of atmospheric circulation anomalies over the western North Pacific between El Niño and La Niña. *J. Climate*, in press.

Ge, X., T. Li, S. Zhang, and M. Peng, 2010: What causes the extremely heavy rainfall in Taiwan during Typhoon Morakot (2009)? *Atmospheric Science Letters*, 11(1), 46-50.

Wen, M., T. Li, R. Zhang, and Y. Qi, 2010: Structure and origin of the quasi-biweekly oscillation over the tropical Indian Ocean in boreal spring. *J. Atmos. Sci.*, Vol. 67, No. 6, 1965-1982.

Ge, X., T. Li, and M. Peng, 2010: Cyclogenesis simulation of Typhoon Prapiroon (2000) associated with Rossby wave energy dispersion. *Mon.Wea.Rev*., 138, 42-54.

Su, J., R. Zhang, T. Li, X. Rong, J. Kug, and C.-C. Hong, 2010: Amplitude asymmetry of El Nino and La Nina in the eastern equatorial Pacific. *Journal of Climate*, 23(3), 605–617.

Manuscript in revision:

Ge, X., T. Li, and M. S. Peng, 2010: Tropical cyclone genesis efficiency: Mid-level versus bottom precursor vortex. *Mon. Wea. Rev*.